P-18

N-31

149921

NASA CASE NO. LAR 14047-1

PRINT FIG. 1

NOTICE

The invention disclosed in this document resulted from research in aeronautical and space activities performed under programs of the National Aeronautics and Space Administration. The invention is owned by NASA and is, therefore, available for licensing in accordance with the NASA Patent Licensing Regulation (14 Code of Federal Regulations 1245.2).

To encourage commercial utilization of NASA-owned inventions, it is NASA policy to grant licenses to commercial concerns. Although NASA encourages nonexclusive licensing to promote competition and achieve the widest possible utilization, NASA will provide the necessary incentive to the licensee to achieve early practical application of the invention.

Address inquiries and all applications for license for this invention to **NASA Patent Counsel, Langley Research Center, Code 143, Hampton, Virginia 23681-0001.**

Serial No.: 07/953,562
09-29/92

LaRC

(NASA-Case-LAR-14047-1) METHOD AND APPARATUS FOR THREE DIMENSIONAL BRAIDING Patent Application (NASA) 18 p

N93-19038

Unclas

G3/31 0149921

METHOD AND APPARATUS FOR THREE DIMENSIONAL BRAIDER

NASA Case No. LAR 14047-1

Braiding apparatus generally consist of a braiding surface upon which travel a number of yarn carrier members which dispense the braiding fibers. Use of a curved braiding surface rather than a flat surface reduces the surface area needed to accomodate a moderate range of braiding angles. Various braiding patterns are possible by manipulation of the carrier member positions on the braiding surface. Many devices use a push/pull mechanism to change the positions or entire rows and columns of carrier members. Other devices use self-propelled carriers traveling in a fixed pattern determined by a preset track arrangement. The designs of these braiding apparatus do not permit fabrication of complex, three-dimensional braided articles because the apparatus provide only a limited range of braid angles the motions of the yarn carriers is generally restricted.

The present invention consists of yarn carrier members which are individually self-propelled in four directions between pivot discs which are located on a curved, segmented and movable braiding surface. The curved, segmented surface effectively allows a much wider range of braiding angles than could be achieved with prior flat or curved braiding surfaces. In addition, the independent motion of the carrier members permits complex motion that is monitored and controlled by computer. The novelty of the present invention encompasses its ability to produce complex three-dimensional braided articles that require a wide range of braid angles and independent yarn carrier movement.

Inventor:	Gary L. Farley
Addrress:	705 Dandy Loop Rd.
	Yorktown, VA 23692
	ss: [redacted]
Employer:	NASA LaRC

Initial Evaluator:	Bland Stein
Serial No.:	07/953,562
Filed:	09-29-92

METHOD AND APPARATUS FOR THREE DIMENSIONAL BRAIDING

Origin of the Invention

The invention described herein was made by an employee of the United States Government and may be used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

Background of the Invention

1. Field of the Invention

This invention relates generally to methods and apparatuses for braiding articles and more specifically to three-dimensional braiding of fibers useful inter alia as fiber reinforced structural preforms.

2. Description of the Related Art

Braiding apparatuses generally consist of a braiding surface upon which travel a plurality of yarn carrier members which dispense the braiding fibers. The braiding fibers generally intersect in an area near the article being braided, hereafter referred to as the braiding zone.

Various braiding surfaces have been developed, with the majority being a simple flat plane, as disclosed in U.S. Pat. No. 4,881,444. Flat surfaces have the disadvantage that extremely large surface areas may be needed to accommodate a moderate range of braiding angles. In addition, flat braiding surfaces cause difficulties in maintaining yarn tension, since carrier members at different braid angles require different length yarns. To address this difficulty, some braiding machines have curved braiding surfaces that attempt to maintain

constant yarn tension by maintaining the carrier members at a constant distance from the braiding zone.

Various braiding patterns are possible by manipulation of carrier member positions on the braiding surface. Many devices use a push/pull mechanism to change the carrier positions of entire rows or columns of carrier members, as disclosed in U.S. Pat. No. 4,885,973. Other devices use self-propelled carriers traveling in a fixed pattern determined by a preset track arrangement, as disclosed in U.S.Pat. No. 4,972,756.

Most braiding machines incorporate some features to maintain yarn tension and to rewind yarn. A common means to accomplish these goals is a coil spring or an electric motor with a friction coupling.

Summary of the Invention

It is accordingly an object of this invention to provide a braiding machine capable of achieving a wide range of arbitrary weave angles in order to fabricate three-dimensional braided articles.

More specifically, this invention is directed to a braiding machine comprising a curved, segmented and movable braiding surface whereby the curved surface effectively allows a wider range of braiding angles than can be obtained with a flat braiding surface of comparable area. A plurality of individually self-propelled carrier members move across the braiding surface by movement from pivot disc to pivot disc. The motion of the carrier members is electronically monitored and controlled by computer. The yarn carriers have dedicated motors which control yarn tension and allow unlimited yarn rewind.

Brief Description of the Drawings

FIG. 1 is a front view of a curved, multi-segmented braiding surface;

FIG. **2** is an end view of the curved braiding surface demonstrating movement of several braiding segments;

FIG. **3** is a perspective of several pivot discs which lie on the braiding surface;

FIG. **4** is a detailed drawing of a typical pivot discs;

FIG. **5** is a drawing of a carrier member assembly; and

FIG. **6** is a cutaway drawing of a typical carrier member assembly.

Description of the Preferred Embodiments

Braided articles of this invention are preferably made on an apparatus that consists of a concave inner braiding surface **10** such as that shown in **FIG. 1**. The braiding surface consists of movable segments **20** which are capable of rotation about an axis **30** through a desired arc of rotation. The concave surface **10** can be any partial or full surface of rotation. The concave inner surface **10** can of course consist of curved and flat portions. The segments **20** are supported and guided in their revolution by stationary guide rails **40**. Rotation of the individual segments **20** may be accomplished by hydraulic or pneumatic actuators, electric motors or other conventional mechanisms which may be located at any convenient location such as between the guide rail **40** and the convex surface of the braiding segment **20**. Pivot discs **50** are situated on the concave surfaces of the braiding segments **20**. The shape of the braiding surface **10**, the mobility of the braiding segments **20** and the individual control of carrier members **150** facilitates the unique placement of fibers that heretofore has been unattainable except by manual manipulation of yarns, as discussed below.

The end view of the braiding apparatus shown in **FIG. 2** illustrates various positions of the segments **20** on the guide rail **40** in relation to the braiding zone **60** formed by the fiber strands of the article **80** being braided. Guide rings **45** secure the segments **20** on the guide rails **40**. Guide

mechanisms **25** such as a grooved wheel are powered by a motor **28**, fixedly connected to movable segments **20**, and travel along guide rails **40**. The motor is powered by a power supply **216** controlled by a computer **215** in the same manner as shown in **FIG. 1**.

FIG. 3 illustrates the layout of evenly spaced, non-translating pivot discs **50** on the concave surface of the braiding segments **20**. The braiding surface **20** consists of an assemblage of pivot discs **50**. Along the flat or singularly curved regions of the braiding segments **20** the pivot discs **50** are evenly spaced. However, on the region of the braiding surface **10** with double curvature some of the rows of pivot discs **50** are omitted. Deleting rows along the doubly curved region of the braiding surface **10** limits the amount of movement between rows that is capable in this region. Each pivot discs **50** is capable of rotation through $^{\pm}180°$ about its center point, i.e., about an axis perpendicular to the concave side of the braiding surface **20** as discussed below. Situated on the pivot discs **50** are linear shafts **90** which can be longitudinally aligned with similar shafts **90** on adjacent pivot discs **50** by rotation of the discs **50**. Non-braiding yarn tubes **75** extend through the braiding segments **20** between the pivot discs **50** to guide unidirectional non-braiding fibers **77** for the braided article **80**. By extending these yarns through the braiding surface, the need for separate tractor/yarn carriers for these yarns is eliminated, thereby further reducing the required braiding area.

FIG. 4 shows additional details of a pivot disc **50**. The surface of the disc **50** has electrical power and sensor contact strips **110**. The linear shaft **90** is flanked by shaft gears **120** which are used to facilitate movement of carrier members **150** discussed below. Below the pivot disc **50** is a stationary support disk **130** which houses a conventional stepper motor or rotary solenoid **135** which turns the pivot disc **50**.

FIG. 5 illustrates a carrier member **150** which travels on the concave side of the braiding surface **10** from pivot disc **50** to pivot disc **50**. The carrier member **150** consists of a yarn carrier **160**, which dispenses a fiber strand **70**,

and a tractor assembly **170**. The tractor assembly **170** has a linear motion bearing **190** which guides the carrier member **150** on linear shafts **90**. Independent propulsion of each carrier member **150** is accomplished by an electric motor **180** which operates a drive gear **200** which intermeshes with shaft gears **120**. The motor **180** is powered through integral electrical power and sensor contacts **210** and is controlled by a computer **215** through a power supply **216**. The computer **215** is programmed to activate power at the carrier members **150**, yarn carriers **160** and braid segments **20** in a sequence determined by the braiding pattern required to construct a given article. When power is turned on at a pivot point electrical current goes from the pivot point through the electrical contacts **110** and **210** and to the motor **180** on the carrier member **150**. The shaft of the motor turns the gears in the gear head assembly and the drive gears **200**. The drive gears **200** mesh with the rack gears **120** on the pivot disc **50**. When the drive gears **200** turn the carrier member **150** moves.

Referring to **FIG. 3**, three different carrier member **150** movements are possible; a carrier member **150** (not shown in FIG. 3) located on pivot disc **50A** may advance forward to pivot disc **50B**, turn to the left or right and advance to pivot disc **50D** or **50E**, and turn $\pm 180°$ and advance to the pivot disc **50C** behind the original location. To advance forward to the next pivot disc **50B** the computer **215** must turn on the electrical power at the first pivot disc **50A**. The carrier member **150** moves forward onto the next pivot disc **50B** until the electrical contacts **210** of the carrier member **150** no longer make contact with the contacts **110** on the first pivot disc **50A**. The computer **215**, through monitoring the current levels on the first pivot disc **50A**, turns the power off at the first pivot disc **50A** and turns on the power at the second pivot disc **50B**. Once the carrier member **150** is completely on the second pivot disc **50B** the computer **215** turns off the power at the second pivot disc **50B**.

To move the carrier member **150** to the pivot discs **50D** or **50E** to the right or left of the original pivot disc **50A**, it is first necessary to rotate both pivot

discs **50A** and **50D** or **50A** and **50E** 90° so that the longitudinal axes of horizontal shafts **90** mounted on the pivot discs **50A** and **50D** or **50A** and **50E** line up with each other. It is important to insure that the pivot discs **50** are rotated in phase so that the carrier member **150** will not be facing the wrong direction after the transfer is complete. The computer **215** turns the electrical power on at the first pivot disc **50A** and the carrier member **150** advances to the designated second pivot disc **50D** or **50E**. When electrical contact no longer exists between the first pivot disc **50A** and the carrier member **150**, the computer **215** turns the electrical power off at the first pivot disc **50A** and on at the second designated pivot disc **50D** or **50E**. Once the carrier member **150** is positioned correctly on the second pivot disc **50D** or **50E**, the computer **215** reorients both pivot discs **50A** and **50D** or **50E**.

In the third case the computer **215** rotates the first pivot disc **50A** 180° and the carrier member **150** advances to the second pivot disc **50C** in a similar manner as is done in the other cases. After the carrier member **150** is correctly positioned onto the second pivot disc **50C**, the computer **215** reorients the first pivot disc **50A**.

FIG. 6 illustrates a yarn carrier **160** which is mounted on the top of a carrier member **150** and dispenses a braiding fiber strand **70**. The fiber **70** is wound on a spool **220** prior to the mounting of the yarn carrier **160** onto the carrier member **150**. Yarn **70** is pulled from the yarn carrier **160** as the carrier member **150** is moved around the braiding surface **10**. Tension is maintained in the yarn **70** to eliminate the beat up process by incorporating a friction coupling **230** and a rewind mechanism **240**. An electric motor or coil spring **240** may be used to rewind the fiber **70**. As the yarn **70** is being pulled out of the carrier **160** the coil spring **240** has already been contracted to its limit. Therefore, tension increases in the yarn **70** until the torque on the spool **220** exceeds the resisting torque supplied by the friction coupling **230**. The yarn **70** is then pulled out of the carrier **160** when the tension in the yarn **70** exceeds the resisting force supplied by the friction coupling **230**. During the braiding

operation there are times when a movement of the carrier member **150** does not result in the extraction of yarn **70** from the carrier **160**. Therefore, to maintain tension in the yarn **70** a rewind mechanism must exist and hence the coiled spring **240**. The coiled spring **240** rewinds the yarn **70** when the tension in the yarn **70** diminishes.

In order to maintain a constant distance between the braiding zone **60** and the braiding surface **10** and to maintain tension of the braiding yarns **70**, a material takeup system **85** is required. Maintaining a constant distance between the braiding zone **60** and the braiding surface **10** permits accurate control of yarn braid angles. Differing preform geometries require different customized takeup systems. Referring to **Fig. 7**, if a flat preform **80** is being braided a clamp **260** secures the top of the preform **80** and a simple set of tension rollers **270** advances the preform **80**. As the preform **80** is braided the tension rollers **270** periodically rotate, in accordance with the braid length, and advance the material. However, if a curved I-beam is braided then the takeup system (not shown) would consist of a series of small movable tension rollers that advance the outer surface of the I-beam at a faster rate than the inner surface of the I-beam.

The programming required to achieve the desired movements of the segments **20**, pivot discs **50** and the carrier members **150** is specifically tailored to the particular braiding pattern. The functions described above define the range of motion for each element and specific operating parameters are implemented straightforwardly.

The computer **215** also controls the position of the movable braiding segments **20**. Certain yarns may be used as "fill" (90 degree) yarns **77** and it may be necessary for the braiding segments **20** to be rotated to facilitate the insertion of the fill yarn **77**. There are other potential examples where the braiding segments **20** must be moved. It is possible that the braiding segments **20** may be rotated such that the carrier members **150** are inverted.

In the braiding process a fault condition could occur with one of the carrier members **150** or yarn carriers **160**. For example, one of the yarn carriers **160** could have a yarn **70** breakage. A fault sensor (not shown) in the yarn carrier **160** signals the computer **215** that a problem existed and the computer **215** could stop the braiding process and signal the operator that a fault condition existed. The computer **215** could, by a graphical means, show which carrier member **150** or yarn carrier **160** signaled the problem. The operator would instruct the computer **215** to move the carrier member **150** to a position where the problem could be corrected or the computer **215** could rotate a braiding segment **20** and the operator manually correct the problem.

Even with the most sophisticated computers and state-of-the-art electronics, the braiding of complex structural preforms will be a slow process. The necessary fabrication efficiency will only be achievable when the entire process of braiding is automated from the original design of the preform to the final braiding of the preform. A designer from a Computer Aided Design (CAD) station preferably designs the structural preform **80**. Prior to braiding the preform **80** the design undergoes computer braiding simulation to validate the design. After the design has been validated, the appropriate number of yarn carriers **160** are wound with yarn **70**. Each yarn carrier **160** contains a specific amount of yarn **70** that is a function of the path the yarn travels in the braided preform **80**. Each yarn carrier **160** is bar coded and stored until the setup of the braider commences. Each yarn carrier **160** is mounted to a carrier member **150**, sensors tested, yarn tension set and then moved onto the braider **20**. The computer **215** directs the movement of the carrier member **150** (as discussed above) to the correct starting pivot disc **50** on the braider surface **20**. A robotic arm (not shown) extracts the end of the yarn **70** from the cap of the yarn carrier **160** and mounts it onto the material takeup system **85**. The process of positioning carrier members **150** and mounting the yarn ends **70** onto the material takeup system **85** is repeated until all the carrier **150** members are correctly positioned onto the braider **20**. When nonbraiding yarns **77** are used

in a preform design the operator inserts these yarns **77** through the appropriate yarn tubes **75** on the braiding surface **20** and the robotic arm attaches the yarn ends **77** to the material takeup system **85**.

Once the braider has been strung the braiding begins. While a preform **80** is being braided additional yarn carriers **160** are being wound with yarn **70**, bar coded and stored for the next preform.

Many improvements, modifications and substitutions will be apparent to the skilled artisan without departing from the spirit and scope of the present invention as described herein and defined in the following claims.

METHOD AND APPARATUS FOR THREE DIMENSIONAL BRAIDING

Abstract of the Disclosure

A machine for three-dimensional braiding of fibers is provided in which carrier members travel on a curved, segmented and movable braiding surface. The carrier members are capable of independent, self-propelled motion along the braiding surface. Carrier member position on the braiding surface is controlled and monitored by computer. Also disclosed is a yarn take-up device capable of maintaining tension in the braiding fiber.

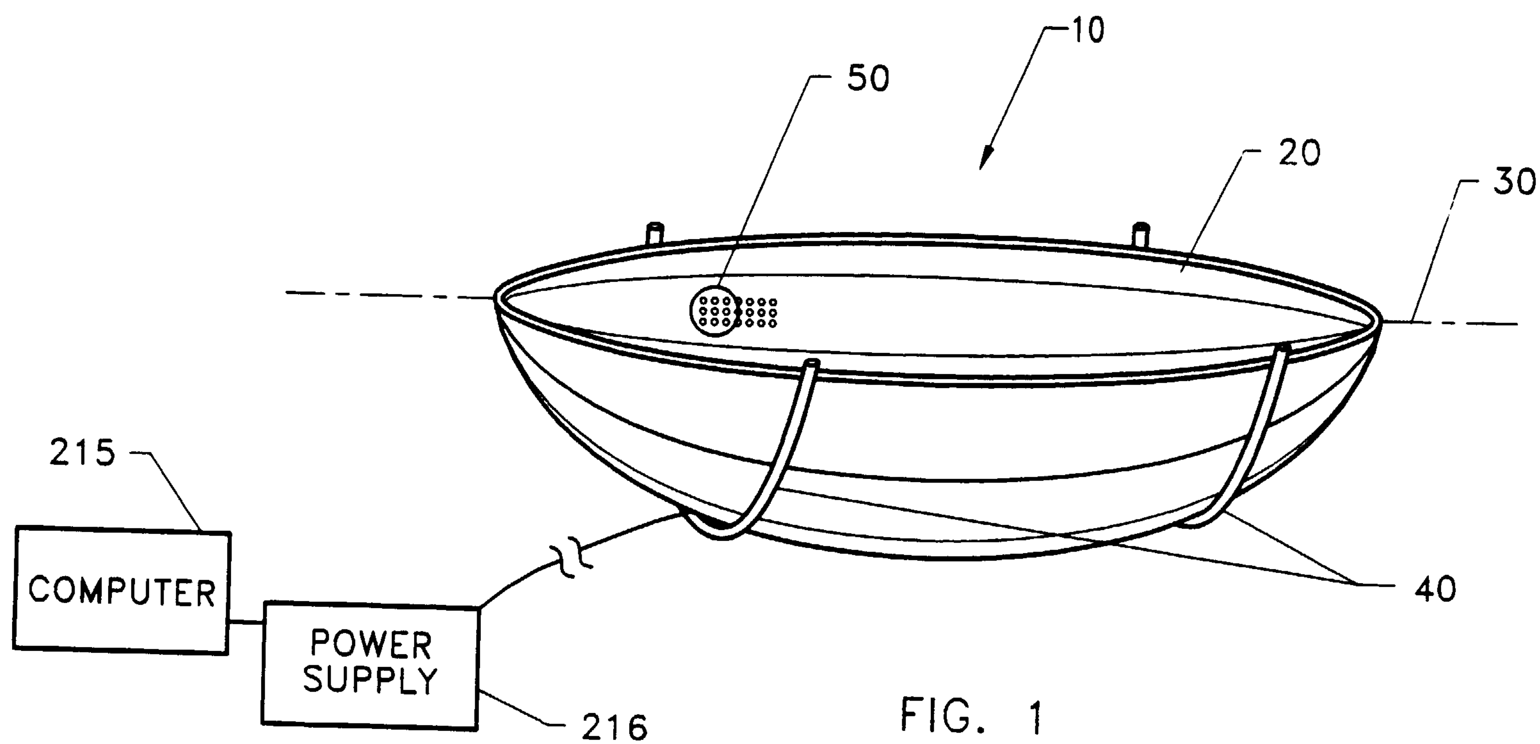

FIG. 1

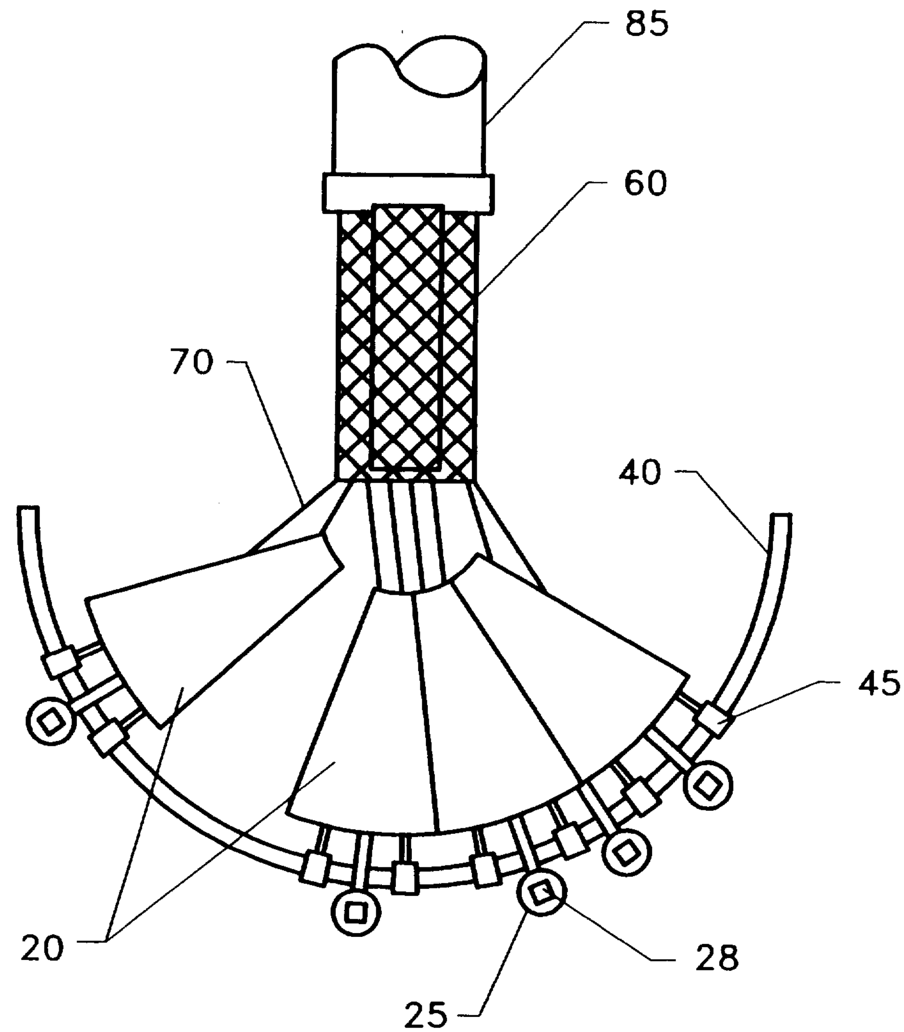

FIG. 2

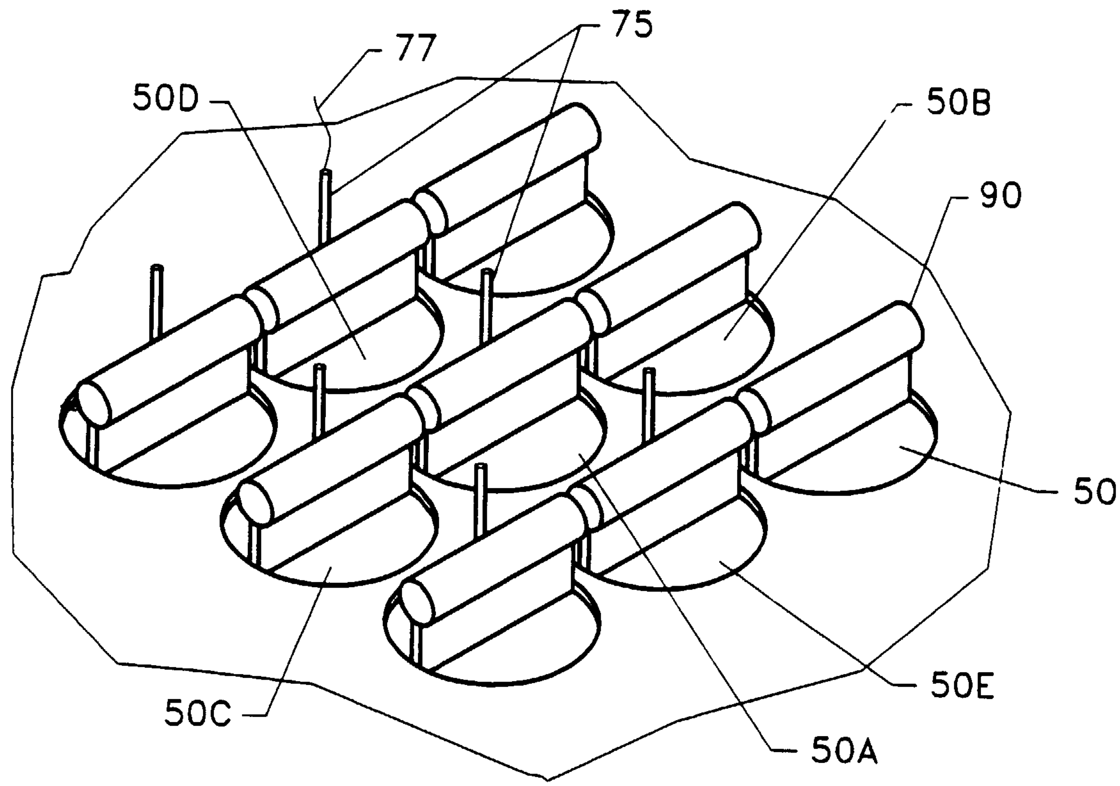

FIG. 3

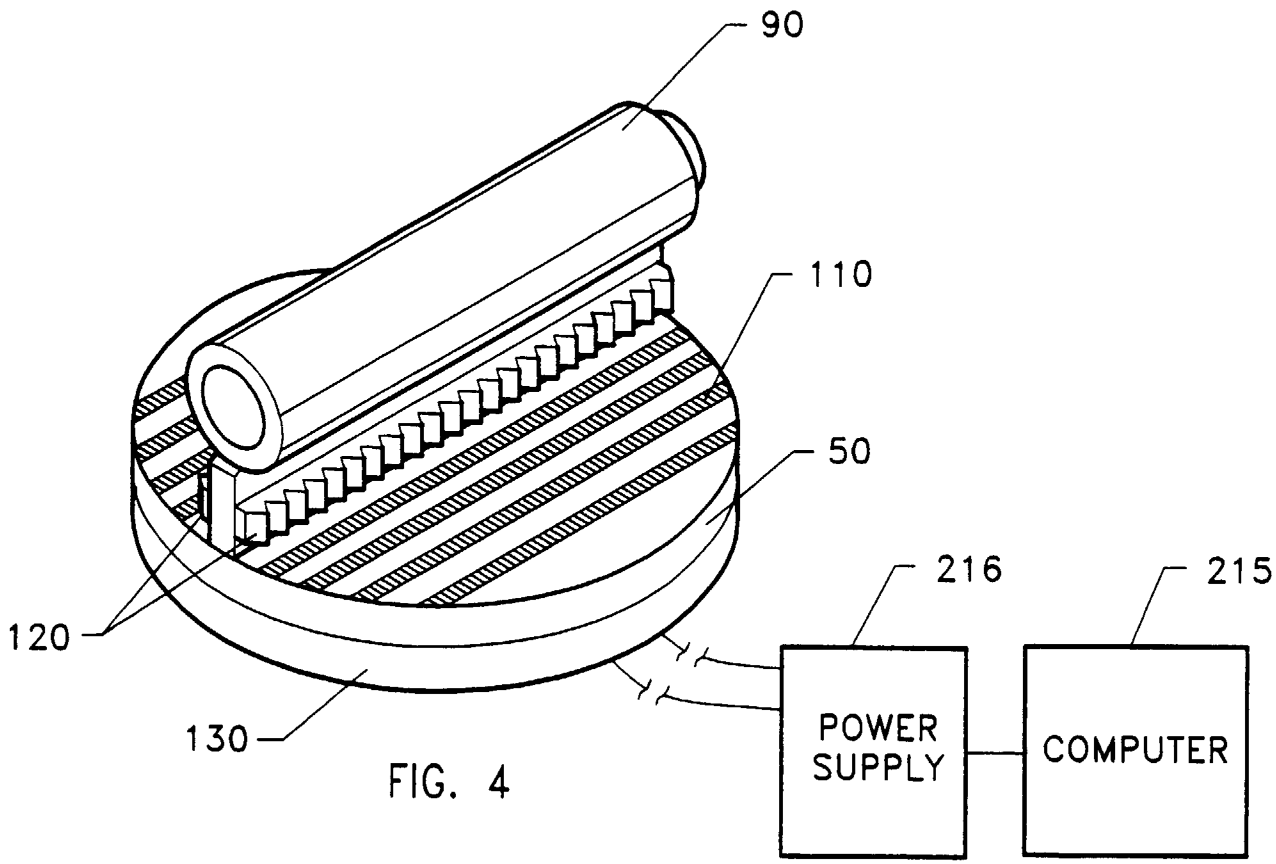

FIG. 4

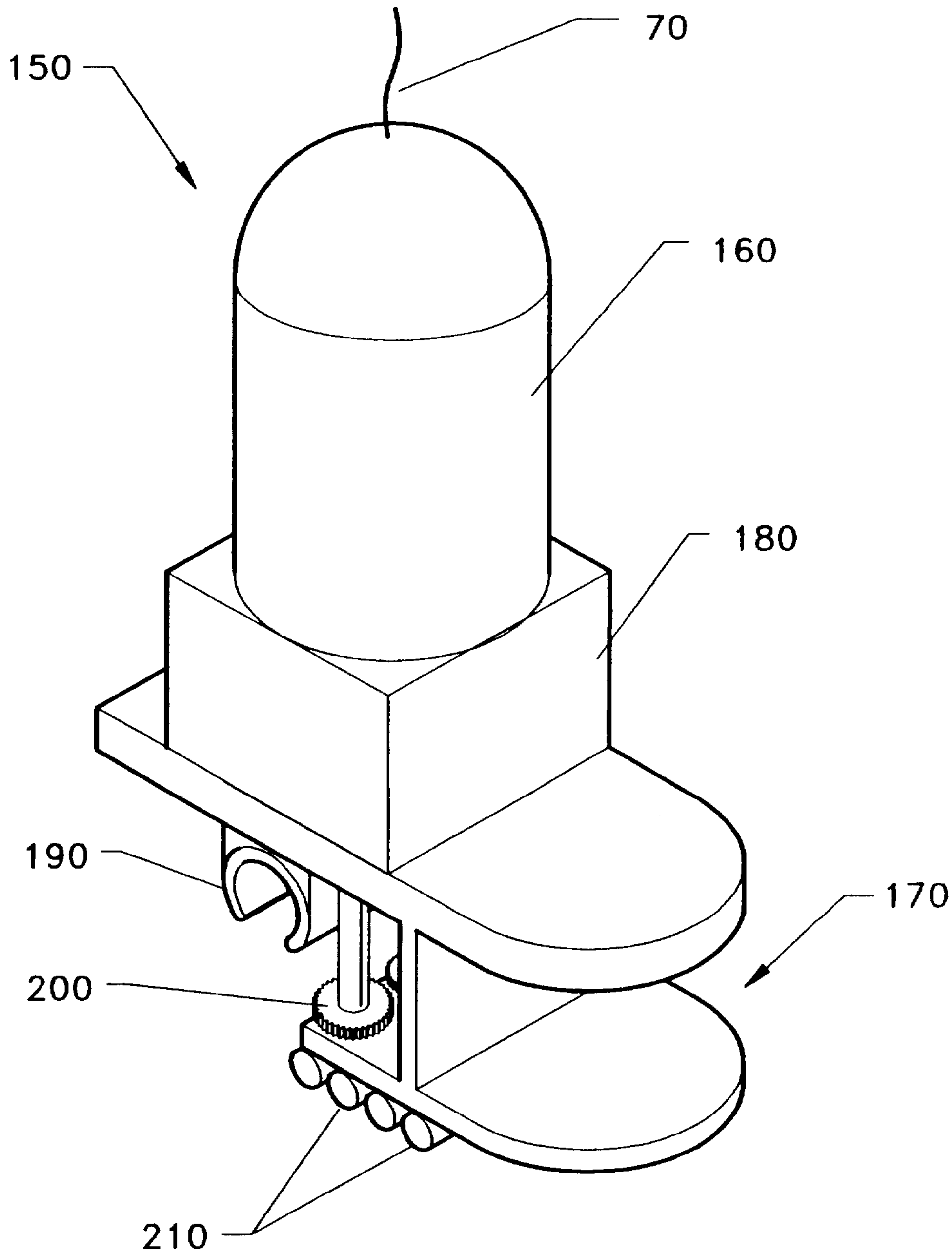

FIG. 5

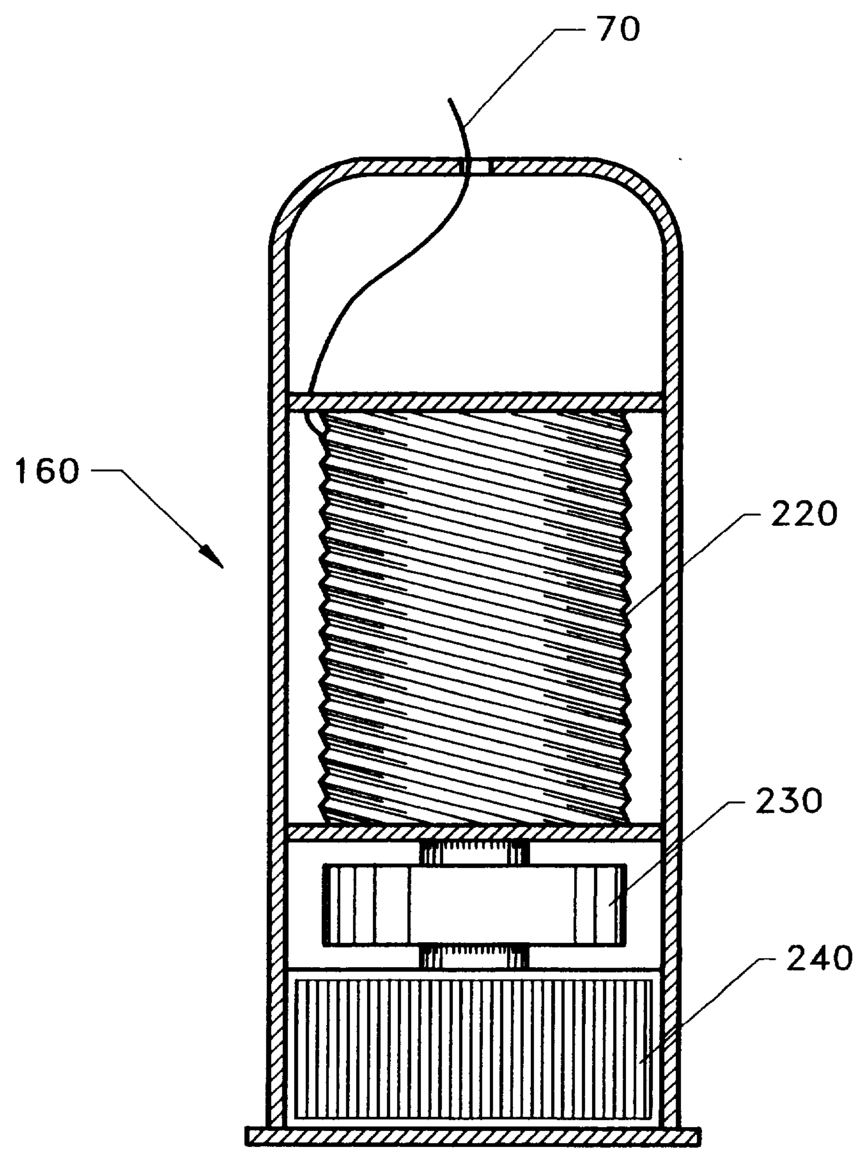

FIG. 6

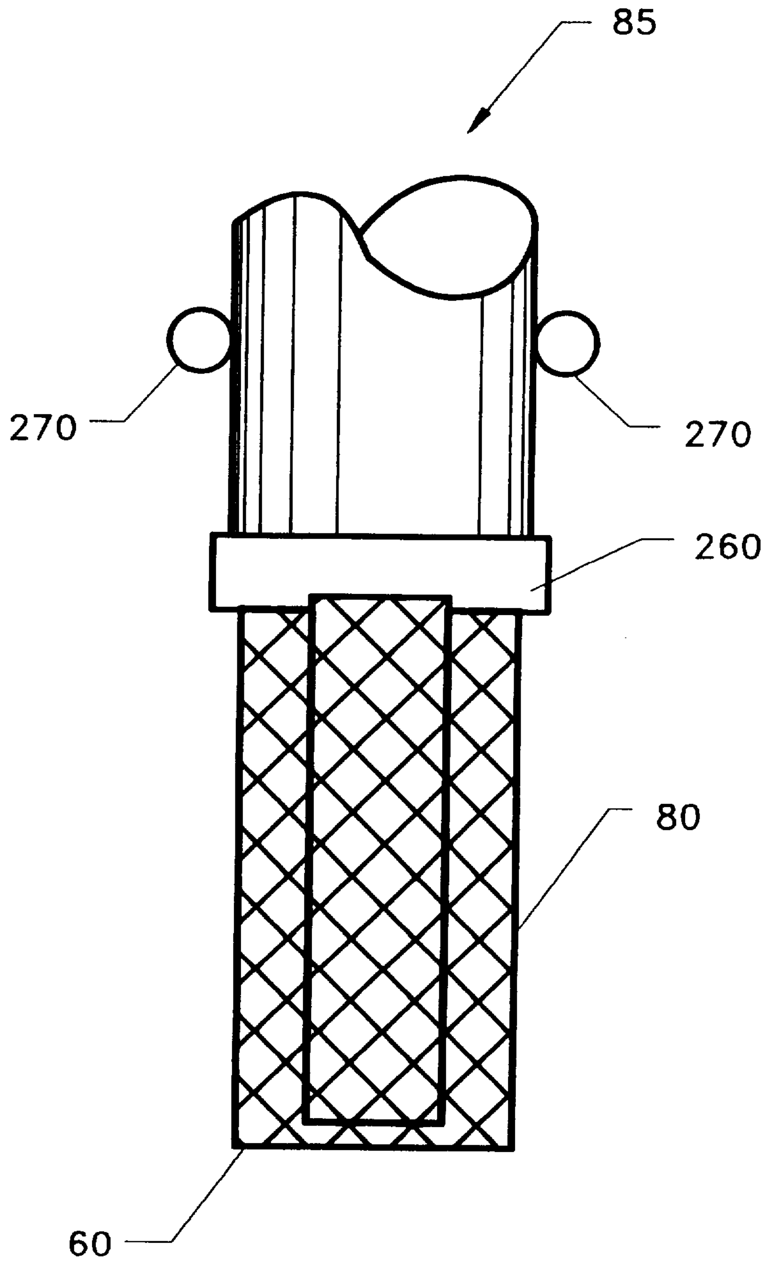

FIG. 7